The Landscape Ecosystem Approach and Conservation of Endangered *Spaces*

by

Burton V. Barnes

Focused on spaces as well as species, the landscape ecosystem approach provides a holistic ecological framework for preserving, conserving, and managing segments of the ecosphere. The approach, as it has been applied in Michigan, has its roots in the southwestern German state of Baden-Württemberg where a comprehensive yet simple ecological method of ecosystem classification and mapping was developed. The ecological approach is well suited for conserving rare and endangered species, preserving and maintaining ecological diversity and biodiversity, and preserving and restoring natural landscapes.

Endangered species and biodiversity are popular concepts. They typically identify for most of us the most important objects in the world—organisms—rather than the ecosystems of which they are one part. Humans and other organisms are dependent and integral parts of the largest "space" we know—the ecosphere. This ecocentric viewpoint, the ecological foundations and theory of the landscape ecosystem approach, as well as insights to its application in conservation and ecosystem management, are well documented in the writings of J. Stan Rowe, Professor Emeritus of the University of Saskatchewan. In practice, landscape ecosystems have been identified, classified, described, and mapped in the field for over four decades in Canada and Germany. This research provides a geographic and ecological framework for use in conservation of ecosystems and organisms at any designated spatial scale.

I will briefly outline below the rationale of the landscape ecosystem approach and define landscape ecosystems drawing primarily from the work of Rowe. I will sketch briefly how we came to adopt the specific approach we use and describe how we go about identifying and mapping landscape ecosystems in the field. I will describe an example of the relationship of the rare and endangered species, the Kirtland's warbler, to landscape ecosystems of its summer breeding grounds.

A Holistic Approach

Using an ecosystem approach means that we focus on wholes, not parts (Rowe 1992)—shifting our focus from animals, plants, soils, esthetics, and other properties of the earth's skin to three-dimensional landscape and waterscape ecosystems that produce these valuable things. The largest of these volumetric units that we know is the earth, i.e., the ecosphere. And nested within it are macro-level, meso-level, and micro-level ecosystems that range from continents and seas to the local landscape type consisting of an atmospheric layer over an earth/water layer with organisms sandwiched between at the surface. However, the gas, solid, and organic phases of the ecosphere are not separate. As Rowe (1992) observes:

Our focus [shifts] from animals, plants, soils, esthetics, and other properties of the earth's skin to three-dimensional landscape and waterscape ecosystems...

"Misled by our dominant sense of sight that operates by separating objects in space, we have divided the Ecosphere into fragments in various ways such as air, water, sediments and organisms or —more commonly and self-centeredly —into 'people' and 'environment.' But we have missed the most important way to divide the Ecosphere for purposes of understanding, management and admiration. The division that makes most ecological sense breaks the air/water/ landform skin of the Earth, at different scales according to purpose, into three-dimensional chunks; geographic ecosystems that include all the essentials: air, water, sediments and soils along with their organisms, yielding the equivalent of giant terrariums and giant aquariums."

In research at the University of Michigan, with teams of graduate students, we have attempted to apply and test this landscape ecosystem approach.

The German Connection

The Baden-Württemberg method, initiated in 1947, features an interdisciplinary team approach (Barnes 1984). As personnel of the state forest research station in Stuttgart, they pioneered the integration of multiple factors (forest history, pollen analysis and paleoecology, geology and geomorphology, geography, climate, soils, vegetation) to identify, classify, describe, and map forest ecosystems. Besides the physical or abiotic site factors, vegetation (pre-settlement natural vegetation of the Period IX of Firbas, 1952), and soil biota were also taken into account. Thus they recognized the multiple layers and volumetric nature of whole ecosystems.

Besides the multi-factor approach, the Baden-Württemberg team also pioneered the use of a comparative, hierarchical approach in classification and mapping. They used multiple scales (i.e., four hierarchical levels) to characterize the landscapes of the state. Thus from the outset they were doing what we call today "regionalization" (Rowe 1991)—partitioning landscapes from above ("top-down" subdivision) as well as aggregation from below (Rowe 1979). For purposes of land preservation or for ecosystem management and environmental monitoring one cannot overemphasize the importance of using multiple scales and particularly a "top-down," mapping approach. In this issue, Dennis Albert (pages 20-25) has described the significance of this approach.

A third major contribution of the German workers was to develop the method of Ecological Species Groups (Sebald 1964, Schlenker 1964, Dieterich 1970) to employ the total vegetation of an area in distinguishing ecosystem types. In this method, one uses groups of species such as herbs, shrubs, mosses (because of similar ecological requirements or tolerances) to indicate certain site-factor complexes, e.g. soil moisture and drainage conditions, soil nutrient relations, light intensity, and soil-reaction (acid vs. basic) gradients. Groups of species tend to be more useful and reliable than single indicator species because reliance is placed on several species. A given ecosystem type is typically characterized by several ecological species groups as well as by a suite of more or less distinctive physiographic, microclimatic, and soil factors.

About the same time, research workers in Canada under the leadership of G. A. Hills, developed a similar system, a "Total Site" approach, using multi-factors at several hierarchical levels (Hills 1952, 1960, 1977; Hills and Pierpoint 1960).

Regionalization and Classification

What is often called "classification" has two separate but related steps that should be distinguished. The first is the *partitioning* of the landscape into units and the second is the *logical grouping* of the resulting parts (Rowe 1991). In the first step, ecosystem types are identified and distinguished by relevant criteria from their surrounding ecosystems. This process of differentiating and mapping units of the landscape is called "regionalization" by geographers (Bailey 1976). At either a broad or local scale this process typically proceeds from above or "top down."

The second step, logical grouping or aggregation of the units based on similarities, is *classification*. What is called "site classification" in the forestry literature may or may not include both regionalization (mapping) and classification. In our work we have used both regionalization and classification in developing a formal "classification" and map for each area.

Distinguishing Among Landscapes

In addition to using the landscape ecosystem approach in teaching, we began in 1976 to conduct research in the field to test and apply a modified version of the Baden-Württemberg method. Since then I have worked with teams of graduate students to develop an approach applicable for local landscapes up to about 25,000 acres in size. In addition, we have developed a regional landscape ecosystem classification and map for the state of Michigan (Albert et al. 1986; pages 21-22 in the article by Albert in this issue).

Fundamentally, the goal is to identify, classify, describe, and map the basic units of nature. The initial research in developing and testing the approach was done at the Cyrus H. McCormick Experimental Forest [see Figure 1, and Box on page15] and the Sylvania Recreation Area in Upper Michigan.

The ecosphere can be segmented into geographic ecosystem types at several scales. At the local scale, these are the basic functional units of nature, and they form a spatial mosaic over the landscape. Some ecosystems are encountered in relatively neat packages, as a bog bounded by upland on all sides. More typically we carve them out of the landscape continuum by the use of appropriate criteria. Although this subjectivity may be a stumbling block for some to the acceptance of landscape ecosystems, it need not be (Rowe 1961). Soils are a good analogy; they are an accepted

Continued on page 16

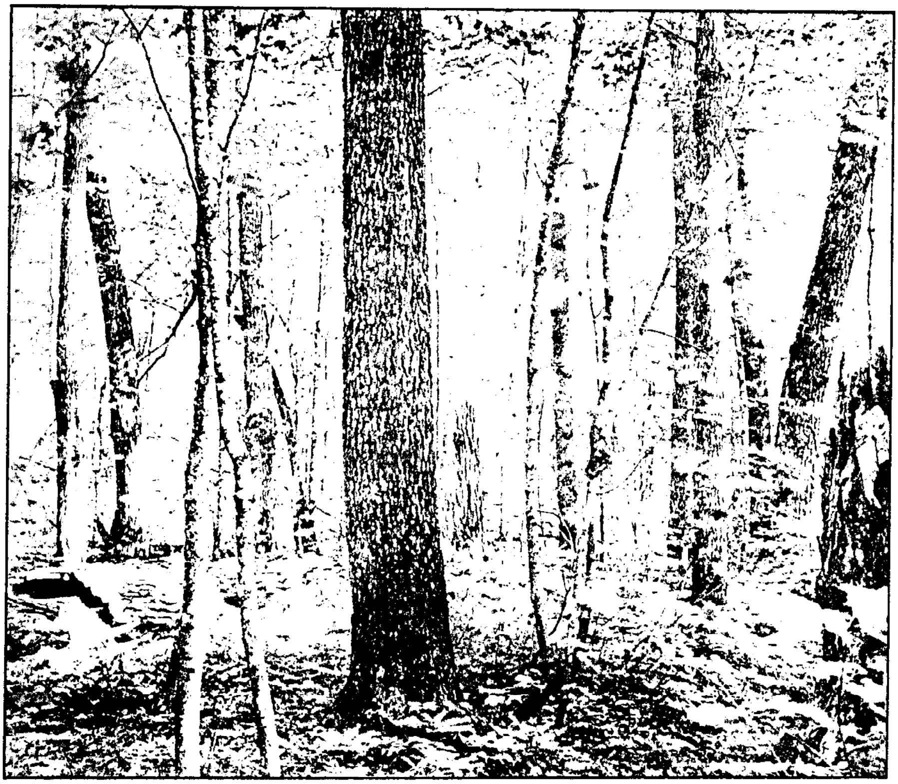


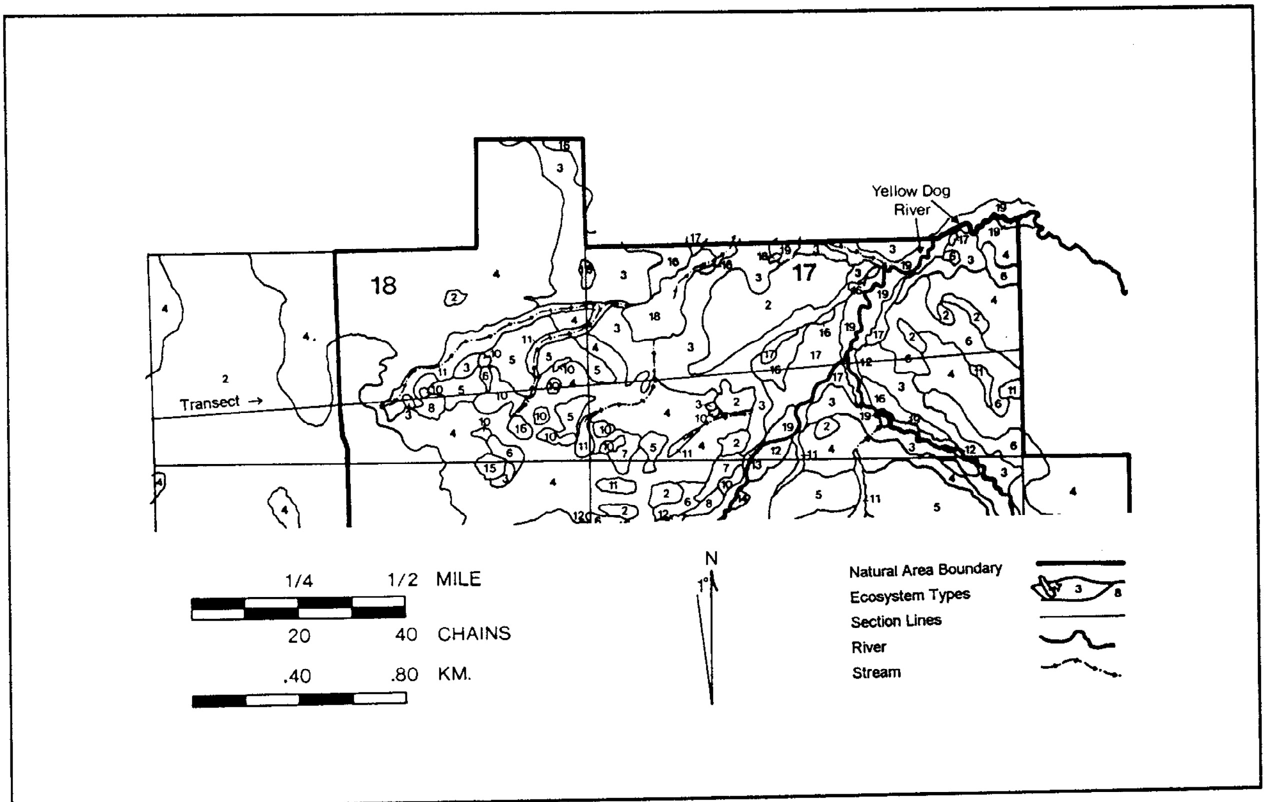
Figure 1. The McCormick Experimental Forest is a sugar maple *(Acer saccharum)* dominated forest.

A Local Ecosystem Map

The Cyrus H. McCormick Experimental Forest, of approximately 17,000 acres, is primarily old-growth northern hardwood and conifer forest. We developed an ecosystem classification and map for the 4,200-acre natural area and then completed the mapping of the entire area using a combination of aerial photographs and ground checking (Barnes et al. 1982).

nated by almost pure sugar maple communities, yet they differ in typographic position, soil, ground cover species (ecological species groups), and certain overstory species.

As the terrain levels out just east of the north-flowing stream, ecosystem 3 prevails on sandy, infertile soil with a high water table. Conifers, especially hemlock (*Tsuga canadensis* (L.) Carr.) and balsam fir (*Abies balsamea* (L.)



(Figure reprinted from *Journal of Forestry* (vol. 80, no. 8) published by the Society of American Foresters, 5400 Grosvenor Lane, Bethesda, MD 20814-2198. Not for further reproduction.)

The map above shows a part of the local ecosystem type map of the McCormick Experimental Forest. A transect running roughly west to east (line above the horizontal E-W section line) illustrates the pattern of ecosystem types in the northeast part of the area. On the west an extensive flat, infertile outwash plain (ecosystem type 2) is dominated by nearly pure, low stature sugar maple (*Acer saccharum* Marsh.). On the east, a rocky ridge, typical of the Michigamme Highlands, runs approximately northwest to southeast. It is identified by the small, recurring ridge-top segments of ecosystem type 10 and the thin-soil ecosystem types 7 and 8, that are often adjacent to such rock outcrops. On the northern slope of the ridge, ecosystem types 4 and 5 predominate. Type 4 typically occurs on sandy upper and mid-slopes and type 5 on loamy lower slopes. These ecosystems are dominated by almost pure sugar maple communities, yet they

Miller), together with red maple (*Acer rubrum* L.) dominate this gently sloping transition zone to the wetlands of the Yellow Dog River. Adjacent to the river are the wetland ecosystems: acid (ecosystem 18) or circumneutral (ecosystem 19) hardwood-conifer swamps and streamside alder (*Alnus rugosa* (Du Roi) Spreng.) (ecosystem 21).

East of the river, and bordering the transition ecosystem 3, is a characteristic alternation of ecosystems: steep, sandy southwest slopes dominated by white pine (*Pinus strobus* L.) (ecosystem 6), and steep, sandy, northeastern slopes dominated by sugar maple (ecosystem 4). These types occur on a series of ice-contact features. The striking difference in vegetation on the same geologic feature and soil parent material illustrates the strong effect of aspect and microclimate in determining vegetational composition.

Continued from page 14

object of scientific study although their boundaries are fixed only by definition.

In the field, one can readily identify and distinguish, as different landscapes, sandy beach ridges supporting jack pine and a nearby peat bog of black spruce. These types differ not only in their plants and animals, but equally important in their form of the land (rolling upland ridges vs. depression), atmosphere (hot vs. cold), and soil parent material (sand vs. peat). Each such ecosystem type not only has spatial *structure*, a predictable position in space and different form, but also complex interactions between its atmospheric, physiographic, soil, and biotic components that we term its *functioning*.

In addition, each of these systems through time undergoes successional changes. These are most obvious in plants and animals as they are influenced by abiotic changes of macro-and microclimate and soil and natural forces such as fire and windstorm. At a given place on the earth's surface different ecosystems have occurred there as a result of the changing interactions of the relatively stable physiography and the more labile components of biota, climate, and soil. Thus we must think of landscape ecosystems in both spatial and temporal scales. And for relatively brief chunks of time, 100-200 years, we can provide useful maps and descriptions of the landscape ecosystems centered around the physiographic features (specific land form and parent material) of a location-specific site.

Thus, following Rowe (1961) we define any single perceptible ecosystem as "a volume of land and air plus organic contents extended areally over a particular part of the earth's surface for a certain time."

How are local landscape ecosystem types differentiated, classified, and mapped using the multi-factor method? No single rigid method is appropriate because of the enormous ecological diversity of different landscapes. However, a general approach is universally applicable. Our job is to sort out the mosaic, differentiating the meaningful ecosystems and in highly disturbed places the sites of landscape ecosystems (Rowe 1991). The methods we have used have been published: McCormick Experimental Forest (Barnes et al. 1982, Pregitzer and Barnes 1984); Sylvania Recreation Area (Spies and Barnes 1985a, 1985b); oak ecosystems of southeastern Michigan (Archambault et al. 1989, 1990); Huron Mountains (Simpson et al. 1990). Readers are directed to the Simpson et al. (1990) paper for the most detailed description of field methods.

Field Methods

To start with we'll assume that the landscape under consideration is a known part of the next higher level in the regional classification of ecosystems and has a relatively homogeneous macroclimate and gross physiography. The first part of the work is to obtain, study, and integrate all information available on the climate, physiography, geology, geomorphology, soils, and vegetation of the area. A first approximation of the classification can be derived by the integration of knowledge of these factors together with a general field reconnaissance of the area.

Areas of markedly different physiography can be distinguished as a starting point. For example, in the glaciated terrain of the Lake States, wetland areas can be distinguished from upland (dryland) areas. And water-laid land forms (flat topography of outwash plains and hilly terrain of ice-disintegration features) can be distinguished from rocky, mountainous terrain or ice-laid glacial till. Thus, at the outset several broad groups of ecosystems can be identified for detailed examination in the field.

Armed with such a first approximation as a working hypothesis, field research is conducted to test the hypothesis and develop a second and more detailed approximation of the classification. Such a "top down" approach of partitioning the area is important early in the research. It is then followed in the field by examination of small, individual types.

Of the ecosystem components, physiography (often termed landform) is the most important in identifying, classifying, and mapping local landscape ecosystems. Physiography is an abbreviation for physical geography which is defined as the surface features of an area (Neufeldt and Guralnik 1988). In our research, physiography is conceived as being characterized by a suite of factors that not only give spatial structure to landscapes, but significantly control ecosystem functioning.

A given landscape ecosystem type would be characterized by these factors. They would include: (1) the specific physiographic feature or land form (mountain, outwash plain, kettle, river terrace, etc.) and in turn many specific characteristics (land form size and shape, slope shape, slope aspect, degree of slope, position on slope, etc.), (2) parent material of the specific land form (rock type, soil particle size, etc.), (3) position of the land form in relation to other land forms, and (4) elevation above sea level. *A priori*, physiography provides the best means of distinguishing ecosystem units at the local level because it is the most stable of ecosystem components and strongly controls regional and local climate, soil moisture, and related nutrient conditions.

In the field, we use an iterative method to continually test and revise the classification by: reconnaissance (over the whole area, at specific points, and along transects), point sampling along transects, plot taking (detailed data taken from temporary or permanent plots), data compilation and study, data analysis, and test mapping. Each successive approximation of the classification is revised by a combination of these methods. Test mapping is typically delayed until the delineation of types is relatively well developed and the physiographic and soil factors and ecological species groups that distinguish the different ecosystems are well understood.

In practice, a team of ecologists would conduct reconnaissance throughout the area, take transects along important topographic gradients of the area, and establish temporary or permanent sample plots. Data on ecosystem components (physiography, soil, vegetation) are taken at points systematically along transects and in sample plots that are established in a stratified random way. We use all ecosystem components simultaneously in the field to examine our working hypothesis of different ecosystem groups and to identify types within groups. In many, if not most cases, the combination of physiographic, soil, and vegetative factors allows us to identify the different ecosystem groups and types and their boundaries.

When we identify an area homogeneous in physiography, soil, and vegetation (i.e., a putative ecosystem type) we establish a sample plot (typically 15 x 30 m) by randomly determining azimuth and distance. When we perceive this same type recurring again in the landscape we sample it again, thereby accumulating a series of plots that characterize what appears to be, by the presence of an entire suite of physiographic, soil, and vegetative factors, an identifiable and mappable ecosystem type. The data are compiled and similarities and differences among putative ecosystem groups and types are examined throughout the field season. Based on our understanding of all factors, types are discarded or merged with other types.

Throughout the field reconnaissance and data taking, ecological gradients of moisture and drainage, nutrients, soil reaction, and light intensity are studied in relation to the occurrence of ground-cover species. Ecological species groups (Spies and Barnes 1985b; Archambault et al. 1989) are thus developed through field observations and data analysis.

At some point in the iterative process, ecosystem test mapping is conducted to determine if we can actually identify and map the types we have distinguished on paper. As Rowe (1980) notes: "The heart of 'ecological classification' is the preparation of maps." Actually it is the process of mapping and, even before actual mapping, the knowledge that the classification must be mappable and explainable, that directs and shapes the classification process and the integration of ecological components. To test the classification in the field, we go through area after area where decisions must be made and boundaries drawn or not drawn. In this process, the reliability of the classification is rigorously tested; the classification is then refined and improved on the basis of the test mapping.

Landscape Ecosystems and Conserving Species

Organisms are notable parts of ecological systems, but rare and endangered organisms cannot be preserved *per se*. As Rowe (1989) observes:

"Organisms do not stand on their own; they evolve and exist in the context of ecological systems that confer those properties called life. The panda is a part of the mountain bamboo-forest ecosystem and can only be preserved as such. The polar bear is a vital part of the arctic marine ecosystem and will not survive without it. Ducks are creatures born of marshes. Biology without its ecological context is dead."

Thus it follows that we should turn attention to the necessity of preserving endangered spaces of wilderness: natural areas, preserves, ecological reserves, and sanctuaries. In preserving the systems we preserve their notable inhabitants. The identification of whole systems by regional and local classification and mapping is useful in determining the characteristics and ecological diversity of different landscapes and their priority for preservation. Furthermore, the biodiversity of a landscape depends upon its ecological diversity.

Secondly, an understanding of whole ecosystems is gained through the process of their differentiation, classification, and mapping. Through better understanding of species-site interactions, life history of species, and their habitat requirements, we gain insights in how to manage populations of a species and its ecological system from which it is inseparable. A case in point is the Kirtland's warbler *(Dendroica kirtlandii)*.

Kirtland's Warbler in a Jack Pine Ecosystem

The Kirtland's warbler is a part of sand outwash plain, jack pine-oak forest landscapes in the north-central part of Lower Michigan, and to paraphrase Rowe, can only be preserved as such. Very little is known of its wintering ecosystems in the Bahamas so that primary attention has focused on its summer breeding grounds. Never considered an abundant bird, populations of the warbler declined from an estimated 1,000 birds in 1961 (Mayfield 1962) to about 460 birds in 1981 (Ryel 1981) and to about 400 in 1971 (Mayfield 1972).

The warbler typically nests on the ground in stands of young (8- to 20-year old) jack pine (*Pinus banksiana* Lamb.) characterized by dense patches of pines (or pines and oaks) interspersed by numerous small openings. Warblers delay colonization of an area until the jack pines reach a minimum height of 6–9 feet and leave an area when the tree crowns shade most of the openings. Although considerable research had been published on the warbler itself (two books and about 200 papers, Ryel 1981), little detailed information was known on what is termed warbler habitat.

The Mack Lake burn of May 5, 1980, (a prescribed burn that got out of control), created the possibility of studying diverse landscapes and the response of the warbler to what was to become a massive increase in summer breeding grounds. The fires covered an area of 23,830 acres surrounding Mack Lake in Oscoda County. According to Simard et al. (1983) the fire: "may have created what in 10 years will be 10,000 to 15,000 acres of prime habitat for the endangered Kirtland's warbler."

At the urging of Dr. Sylvia Taylor (see Taylor's paper in this issue pages 26-29), we undertook the study of the landscape ecosystems of the central part of the Mack Lake burn—their physiography, microclimate, soil, and vegetation that might favor colonization by the warbler. The overall objective was to establish a framework of local landscape ecosystems as the basis for understanding warbler occurrence and behavior.

We found that the outwash terrain of the Mack Lake basin was surrounded on all sides, except the west, by relatively high moraines and ice-contact landforms. The basin surrounding Mack Lake was a series of flat to rolling, pitted outwash terraces of increasing elevation, culminating in the south to sharply dissected ice-contact terrain. We distinguished arbitrarily two major landscapes

Figure 2. Jack pine *(Pinus banksiana)* in high-level outwash, Mack Lake basin, 1986. Photo by Burton V. Barnes.

i.e., groups of ecosystems: high-level outwash and ice-contact terrain in the more southerly part of the basin and low-level outwash in the central basin surrounding Mack Lake itself. Within each of these groups of ecosystems we distinguished and described several local ecosystem types based on physiography, microclimate, soil, and ground-cover vegetation (Barnes et al. 1989; Zou et al. 1992).

The high-level outwash terrain was warmer and had several ecosystems with better soil (higher soil moisture content because of either fine sand or fine-textured bands). The low-level outwash, a large frost pocket in the center of the basin had a colder climate and ecosystems with poorer soils. When we initiated research in 1986, the jack pines and northern pin oaks (*Quercus ellipsoidalis* E. J. Hill) of the high-level terrain were in many places markedly taller, denser, and of more patchy occurrence than those in the low-level terrain (see Figures 2 & 3). Also, major differences in ground-cover vegetation were found between high-level and low-level terrain and among the local ecosystems within each.

In the first year of our research, 1986, the warblers first colonized the burn when all trees were seven years old from seed. Seventy percent of the 14 birds occupied the high-level terrain and only 30% the low-level terrain. In 1987 and 1988 about 60% of the warbler occurrence (28 birds in 1987 and 78 in 1988) was in the high-level terrain. We attributed the greater initial occurrence in the high-level terrain to markedly different physiography (including parent material) which resulted in warmer climatic conditions and better soil conditions. These in turn resulted in markedly taller jack pines, a characteristic that wildlife biologists perceive to be critical for the initial colonization of an area.

As more and more of the low-level terrain has become suitable habitat (taller jack pine and oak trees) and the warbler population increased markedly, proportionally more warblers colonized the low-level terrain. In 1991 and 1992, over 60% of the warblers (208 and 250, respectively) were found in the low-level terrain.

Not only is warbler occurrence related to the ecological conditions of the two ecosystem groups, but their occurrence could also be related to specific ecosystem types within each of the groups (Barnes et al. 1989; Zou et al. 1992). For example, Zou (1988) found that patchiness (a contagious distribution of jack pine trees as compared to a random or systematic pattern), a major criterion of good warbler habitat, was characteristic of the ecosystem types supporting warblers but not of ecosystems uninhabited by warblers.

In addition, in 1988 Zou (Zou et al. 1992) studied the occurrence of territories of 38 warblers in relation to specific ecosystem types. The warblers in 1988 (as in 1987) occurred in the same five of the 11 ecosystems identified for the area.

The territories were closest together in two ecosystems of the high-level terrain; the average distance from a singing male territory to its closest neighbor was 269 m for one ecosystem and 365 m for the other ecosystem. In contrast, a widespread ecosystem of the low-level terrain supported the most warblers, but their territories were more widely separated, 435 m. Compared to the two high-level ecosystems, the low-level ecosystem exhibited a colder microclimate, more drought-prone soil, shorter and more widely spaced trees, and less diverse ground-cover vegetation. The high-level ecosystems exhibited relatively dense populations of warblers for the initial years, but as the pines and oaks in the low-level area increased in size, a shift in the population has occurred from the high-level to the low-level landscape. Using the landscape ecosystem approach we can predict which ecosystems will be first colonized and the pattern of colonization to other ecosystems in time.

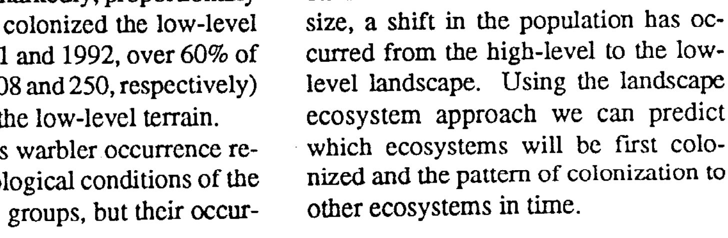


Figure 3. Small jack pine *(Pinus banksiana)* in low-level outwash, Mack Lake basin, 1986. Photo by Burton V. Barnes.

Providing an Ecological Framework

The landscape ecosystem approach applied in the Mack Lake basin indicates that the pattern of warbler occurrence in space, and time as well, is grounded in the basic glacial geology and physiography of the landscape which in turn affects microclimate, soil moisture and nutrient status, the growth and patchiness of jack pine and oak, and the composition and density of ground-cover vegetation.

The approach provides the understanding of whole landscapes such that the best areas for warbler management (by prescribed burning or planting) could be selected to maintain a high warbler population. Landscapes of different and adjacent physiographic features could be selected to maintain the warblers in a given area for the longest possible time, thereby concentrating the management efforts and reducing costs.

The landscape ecosystem approach also provides the ecological framework for detailed studies of warbler nesting relations, reproductive behavior, foraging, and population dynamics. Experience with the warbler showed that it is not just the biology of the species that is important, but more fundamentally understanding whole systems of which the warbler is an integral part.

In summary, understanding earth-surface ecosystems provides an ecological framework and common ground for all resource users. The ecosystem approach is a new way of sensing the world; we shift our focus from species to spaces. Rowe (1992) sums it up this way:

"The primary concern becomes maintenance of landscapes and waterscapes *as complete ecosystems*, because the only way to assure the sustained yields of forests, wildlife and water, now and in the future, is to keep them and all their parts in a healthy state. This is the essence of the *ecosystem approach*. It means that everyone attends to the conservation and sustainability of ecosystems, instead of sharply focusing on the productivity of individual or competing resources—which has been our traditional mode of operation."

Literature Cited

Albert, D.A., S.R. Denton, and B.V. Barnes. 1986. Regional Landscape Ecosystems of Michigan. School of Natural Resources, University of Michigan. Ann Arbor. pp.32.

Archambault, L., B.V. Barnes, and J.A. Witter. 1989. Ecological species groups of oak ecosystems of southeastern Michigan, USA. Forest Science 1058-1074.

Archambault, L. B.V. Barnes, and J.A. Witter. 1990. Landscape ecosystems of disturbed oak forests of southeastern Michigan, USA. Can. J. Forest Research 20:1570-1582.

Bailey, R.G. 1976. Ecoregions of the United States. Department of Agriculture, U.S. Forest Service, Ogden, Utah.

Barnes, B.V. 1984. Forest ecosystem classification and mapping in Baden-Württemberg, West Germany. pp.49-65 in J.G. Bockheim (ed.) Proc. Symposium: Forest Land Classification: Experience, Problems, Perspectives. N.C.R.-102 North Central Forest Soils Committee, Society of American Foresters, USDA Forest Service, and USDA Conservation Service, Madison, WI. March 1984.

Barnes, B.V., K.S. Pregitzer, T.A. Spies and V. Spooner. 1982. Ecological forest site classification. J. Forestry 80:493-498.

Barnes, B.V., C. Theiss and X. Zou. 1989. Final report. Ecosystem structure and vegetation of the Mack Lake burn: A framework for understanding the occurrence and behavior of Kirtland's warbler . Report to Michigan Department of Natural Resources. February 1, 1989. 48 pp.

Dieterich, H. 1970. Die Bedeutung der Vegetationskunde für die forstliche Standortskunde. Der Biologieunterricht 6:48-60.

Hills, G.A. 1952. The classification and evaluation of site for forestry. Ontario Dept. Lands and For., Res. Rept. 24. 41 pp.

Hills, G.A. 1960. Regional site research. Forestry Chronicle 36:401-423.

Hills, G.A. 1977. An integrated iterative holistic approach to ecosystem classification. pp. 73-97 in J. Thie and G. Ironside (eds.). Ecological (Biophysical) Land Classification in Canada. Ecological land classification series, No. 1, Lands Directorate, Env. Canada, Ottawa.

Hills, G.A., and G. Pierpoint. 1960. Forest site evaluation in Ontario. Ontario Dept. Lands and For., Res. Rept. 42. 64 pp.

Mayfield, H.F. 1962. 1961 decennial census of Kirtland's warbler. Auk 79:173-182.

Mayfield, H.F. 1972. Third decennial census of Kirtland's warbler. Auk 89:262-268.

Neufeldt, V. and D.B. Guralnik (Eds.). 1988. Websters New World Dictionary. 3rd College Edition. Simon and Schuster. New York. 1574 pp.

Pregitzer, K.S., and B.V. Barnes. 1984. Classification and comparison of the upland hardwood and conifer ecosystems of the Cyrus H. McCormick Experimental Forest, Upper Peninsula, Michigan. Can. J. Forest Research 14:362-375.

Rowe, J.S. 1961. The level-of-integration concept and ecology. Ecology 42:420-427.

Rowe, J.S. 1979. Revised working paper on methodology/philosophy of ecological land classification in Canada. pp. 23-30 In C.D.A. Rubec (ed.), Proc. Second Meeting Canada Committee on Ecological (Biophysical) Land Classification, April 4-7, 1978, Victoria, B.C. Lands Directorate, Environment Canada, Ottawa.

Rowe, J.S. 1980. The common denominator of land classification in Canada: an ecological approach to mapping. Forestry Chronicle 56:19-20.

Rowe, J.S. 1989. What on earth is environment? The Trumpeter 6:123-126.

Rowe, J.S. 1991. Forests as landscape ecosystems, implications for their regionalization and classification. pp. 3-8 in D. L. Mengel and D. T. Tew (eds.). Ecological Land Classification: Applications to Identify the Productive Potential of Southern Forests. Proc. of a Symposium. USDA For. Serv. Southeastern Forest Exp. Sta., Gen. Tech. Report SE-68. 149 pp.

Rowe, J.S. 1992. The ecosystem approach to forestland management. Forestry Chronicle 68:222-224.

Ryel, L.A. 1981. Population change in the Kirtland's warbler. Jack-Pine Warbler 59:76-91.

Schlenker, G. 1964. Entwicklung des in Sudwestdeutschland angewandten Verfahrens der forstlichen Standortskunde. Pp. 5-26 in Standort, Wald und Waldwirtschaft in Oberschwaben. "Oberschwabische Fichtenreviere." Stuttgart.

Sebald, O. 1964. Okologische Artengruppen fur den Wuchsbezirk "Oberer Neckar." Mitt. Vereins f. forstl. Standortsk. u. Forstpflz. 14:60-63.

Simard, A.J., D.A. Haines, R.W. Blank, and J.S. Frost. 1983. The Mack Lake fire. USDA For. Serv. Gen Tech. Rep. NC-83. North Central For. Exp. Sta., St. Paul, MN.

Simpson, T.B., P.E. Stuart, and B.V. Barnes. 1990. Landscape ecosystems and cover types of the Reserve Area and adjoining lands of the Huron Mountain Club, Marquette Co., MI. Huron Mountain Wildlife Foundation Occasional Paper No. 4. 128 pp.

Spies, T.A. and B.V. Barnes. 1985a. A multi-factor ecological classification of the northern hardwood and conifer ecosystems of Sylvania Recreation Area, Upper Peninsula of Michigan. Can. J. Forest Research 15:949-960.

Spies, T.A. and B.V. Barnes. 1985b. Ecological species groups of upland northern hardwood-hemlock forest ecosystems of the Sylvania Recreation Area, Upper Peninsula of Michigan. Can. J. Forest Research 15:961-972.

Zou, X. 1988. Pattern of jack pine occurrence in ecosystems of Kirtland's warbler summer habitat at Mack Lake, northern Lower Michigan. Master's Thesis, University of Michigan, School of Natural Resources. 91 pp.

Zou, X., C. Theiss, and B.V. Barnes. 1992. Pattern of Kirtland's Warbler occurrence in relation to the landscape structure of its summer habitat in northern Lower Michigan. Landscape Ecology 6:221-231.

Burton V. Barnes is the Stephen H. Spurr Professor of Forest Ecology in the School of Natural Resources and Environment at the University of Michigan, Ann Arbor, MI.